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High Speed Vessel Medical Limited Objective Experiment

Noise Assessment and Noise Reducing Stethoscope Field Test

by

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Commanding Officer
NAVSUBMEDRSHCLAB

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ADMINISTRATIVE INFORMATION

This investigation was conducted under Research Work Unit #50306. The study protocol NSMRL.2003.0009 was approved by the Naval Submarine Medical Research Laboratory Institutional Review Board in compliance with all applicable Federal regulations governing the protection of human subjects.

The views expressed in this report are those of the author(s) and do not reflect the official policy or position of the Department of the Navy, Department of Defense, or the U.S. Government. This report was approved for publication 26 August 2006 and designated Naval Submarine Medical Research Report No. MR# 06-01.

BACKGROUND

Naval Submarine Medical Research Laboratory has historically conducted research to make optimal use of auditory information in sonar displays. Throughout that pursuit, interference from airborne sound in the listening environment has been a major issue. Even with the highest signal fidelity, if the presented signal is masked by airborne sound, it becomes useless, no matter how potentially relevant. Success in surmounting such environmental impediments using active noise cancellation has lead to the realization that shipboard spaces may be habitable by hearing-risk standards, yet not operationally suitable for critical mission tasks. A logical extension of that auditory display work has been the detection of visceral sounds in a noisy environment using stethoscope devices. Since visceral sounds are surprisingly similar to sonar information, the task of detecting either is quite similar. In both instances, the acoustic signal generated at the source is rich in acoustic information, yet a combination of both poorly processed and seriously masked acoustic signal lead to alternate, more technically complex, sources of information (such as ECG over stethoscope or oscillograph). Unfortunately, vital information is lost in the transformation.

Digital signal processing has suddenly opened up the auditory detection, display and transmission of information in inherently noisy environments. This is most apparent in the explosion in the use of cellular telephones in every conceivable location. Voice recognition software is expected to function perfectly with the poorest fidelity handsets in every noise environment; environments that were previously engineered without regard for anything except hearing damage. It is in that setting that our operational task of developing a stethoscope, of higher fidelity that can function in noise, has evolved.

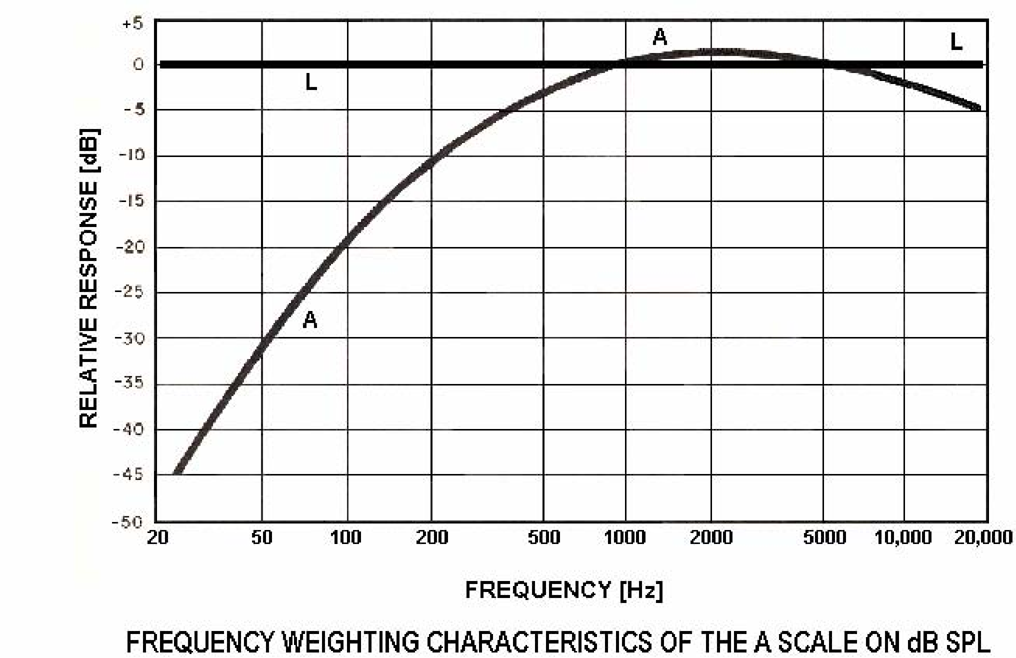

Figure 1. Bandwidth characteristics of the A weighting scale vs. unweighted SPL.

Engineering specifications for environmental noise are all set in A weighted sound measurements to anticipate potential for permanent hearing damage, but these safety-relevant specifications have come to overshadow the more relevant–and more revealing–*unweighted* Sound Pressure Level (SPL) measurements. Figure 1 is a schematic representation of the response characteristics of these two scales. A more detailed description is presented in Appendix A. Readers unfamiliar with sound measurement are encouraged to read that information.

The fact that hearing is less sensitive in the lower frequencies should not be used as justification for ignoring their presence. Once removed from measurement requirements by using the A scale, these lower frequencies have been ignored during noise reduction. Unfortunately, when the acoustic energy to be detected lies in this less sensitive region, not only is the signal near threshold, it has been severely masked by competing environmental noise. Once allowed to exist, these lower frequency components have a far wider dispersion than higher frequencies. Consequently, they cannot be reduced by slightly repositioning the listening task, as would be the case for higher frequencies.

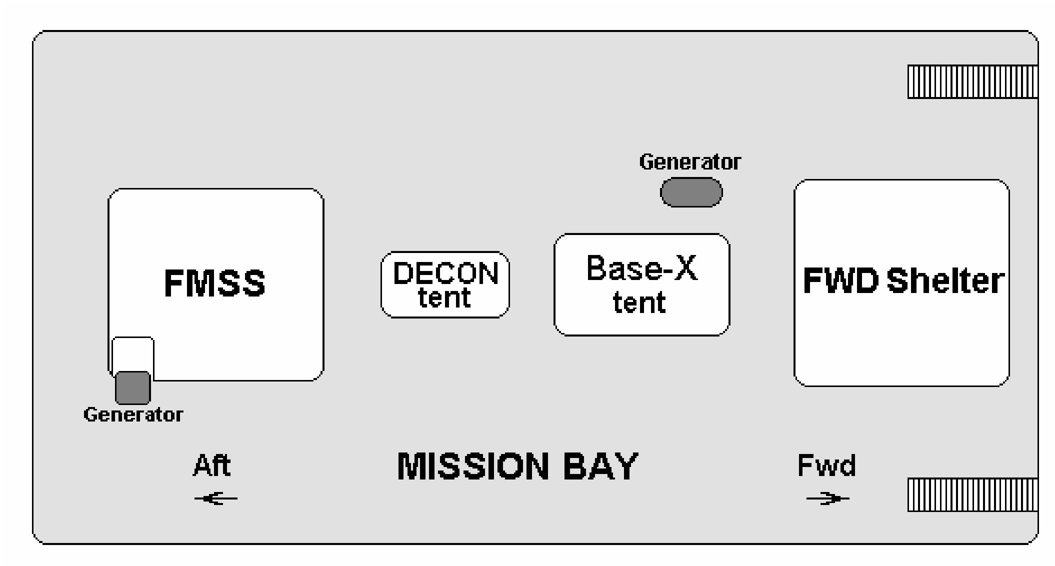

Figure 2. Plan view of Mission Bay operational layout during HSV-2 SWIFT LOE.

The medical Limited Objective Experiment (LOE) was a valuable opportunity to both evaluate the noise environment in spaces not designed for habitation, and to simultaneously test a pre-production noise-reducing stethoscope in a controlled setting under operationally-relevant shipboard noise conditions. Figure 2 is a schematic representation of the layout of the acoustically-relevant components in the mission bay aboard High Speed Vessel (HSV)-2 Swift during the operability evaluation.

METHODS

AIRBORNE SOUND MEASUREMENT

Airborne sound measurements were taken while underway December 14-16, 2004 using a Brüel & Kjær Type 2250 Hand-held Analyzer. All measurements were simultaneously gathered in 1/3-octave bands, within the 11Hz to 22kHz bandwidth, using a 20 sec signal averaging or integration time. For comparative purposes, the overall unweighted SPL levels (LZeq) and the A scale weighted (LAeq) sound level values are provided for that same integration period.

Stored results of those calibrated measurements were digitally transferred into graphing software and are plotted in all subsequent figures. Center frequencies of the standard 1/3-octave bands are listed across the X axis, along with LZeq and LAeq values. Except for LAeq, all the plotted levels are dB SPL unweighted. Levels are designated as "eq" by standard convention, since they are based on a 20 sec integration time.

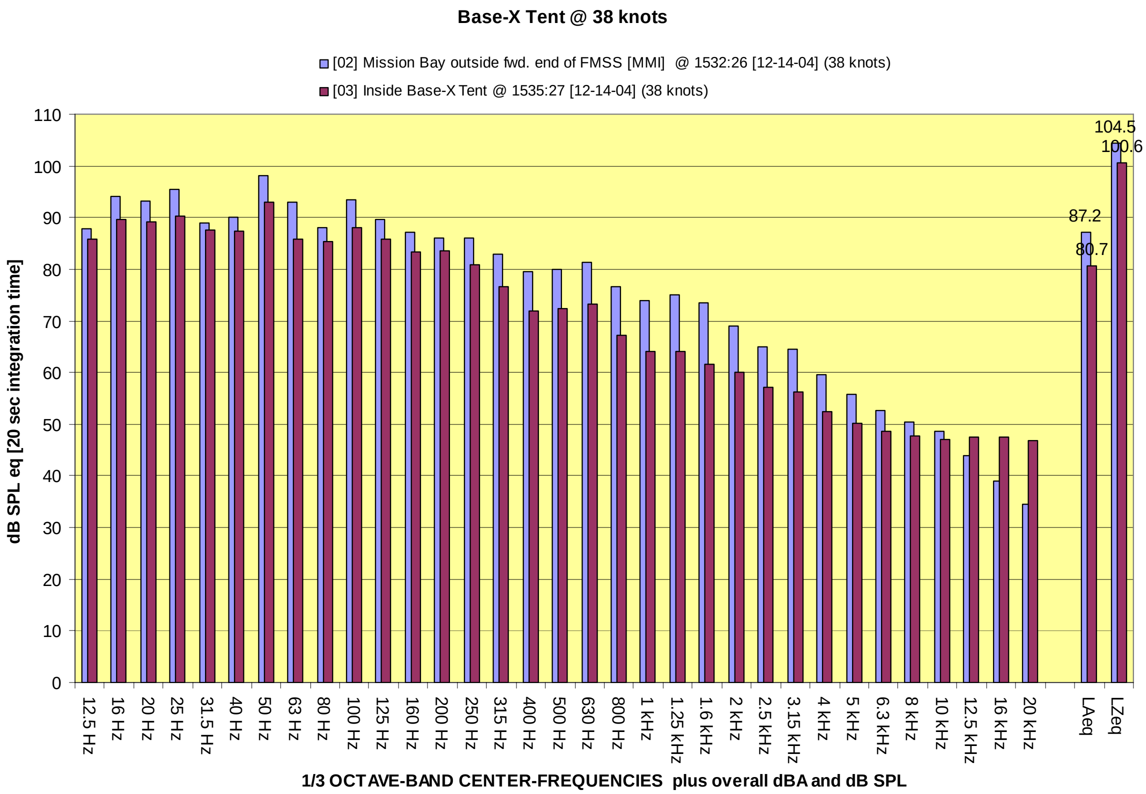

Figure 3. Sound pressure levels measured inside and outside the Base-X Tent @ 38 knots.

Figure 3 compares airborne levels inside the Base-X Tent to those outside in the mission bay @ 38 knots. In this and all subsequent figures, note the dramatic difference in overall dB SPL compared to dBA, due to the low frequency components that are weighted out of the A scale measurement. Unweighted levels were reduced from 104.5 dB SPL outside the

tent to 100.6 dB SPL inside, vs. 87.2 dBA outside to 80.7 dBA inside. Environmental spaces are characteristically evaluated only for airborne noise relevant to hearing damage.

Figure 4 compares levels taken inside the Future Medical Shelter System (FMSS) @ 38 knots against those immediately outside. Note that there is only a 4.5 dB reduction in dB SPL inside the FMSS, but a 10 dB reduction in dBA levels. There is little noise reduction in the 63 to 100 Hz 1/3-octave bands. In both Figure 3 and Figure 4, the overall LZeq levels outside/inside the two shelters (104.5 outside/100 - 100.6 inside) are surprisingly comparable. During both measurement periods, the A weighted levels outside in the mission bay were expectedly equivalent (87 dBA), but the FMSS would be perceived as quieter inside (76.7 dBA) than the BASE-X tent (80.6 dBA).

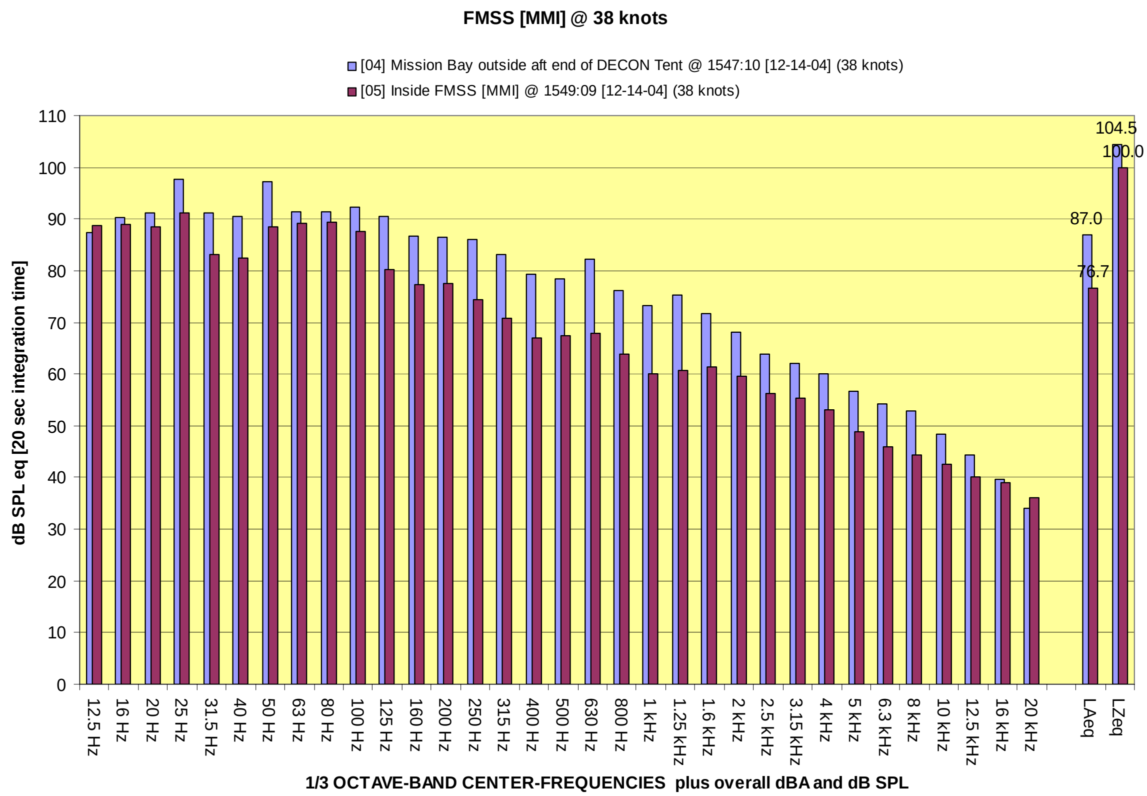

Figure 4. Sound pressure levels measured inside and outside the FMSS @ 38 knots.

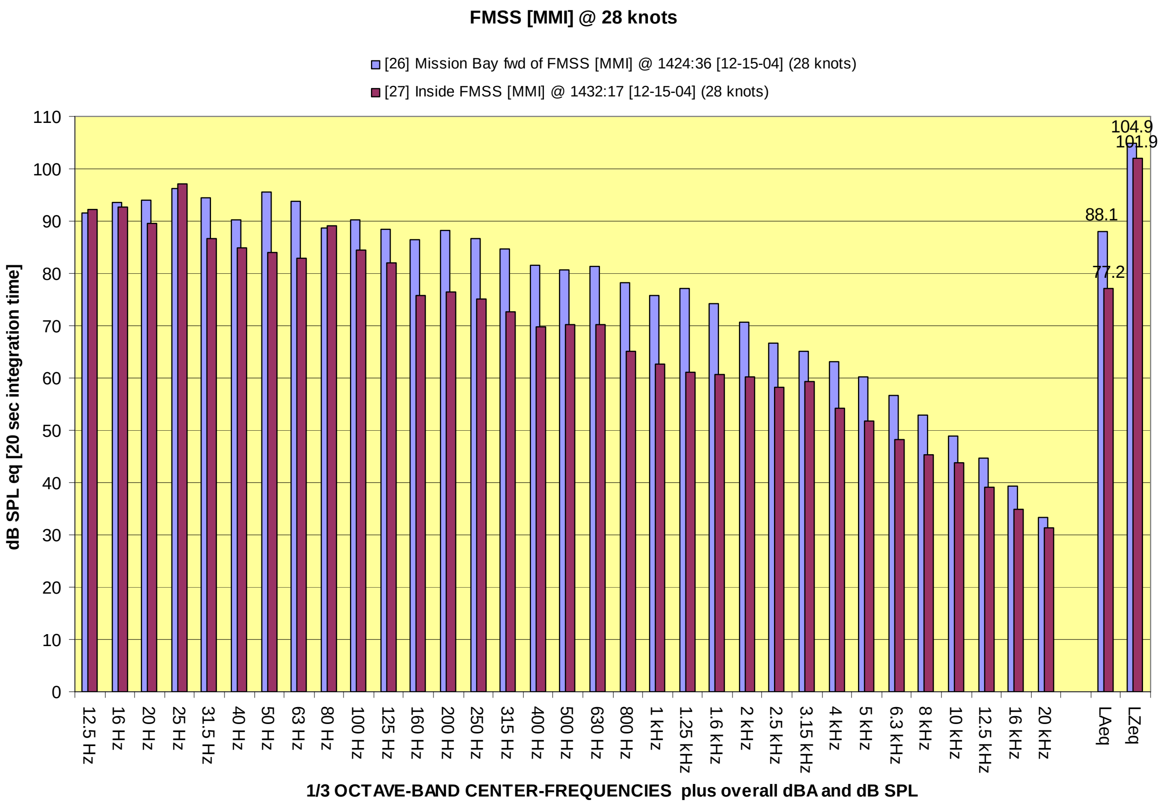

Figure 5. Sound pressure levels measured inside and outside the FMSS @ 28 knots.

Figure 5 compares levels taken inside the FMSS @ 28 knots against those immediately outside. Despite a 10 knot reduction in speed, the inside/outside levels, both broadband (104.9/101.9) and A weighted (88.1/77.2), are nearly identical to those at 38 knots shown in Figure 4.

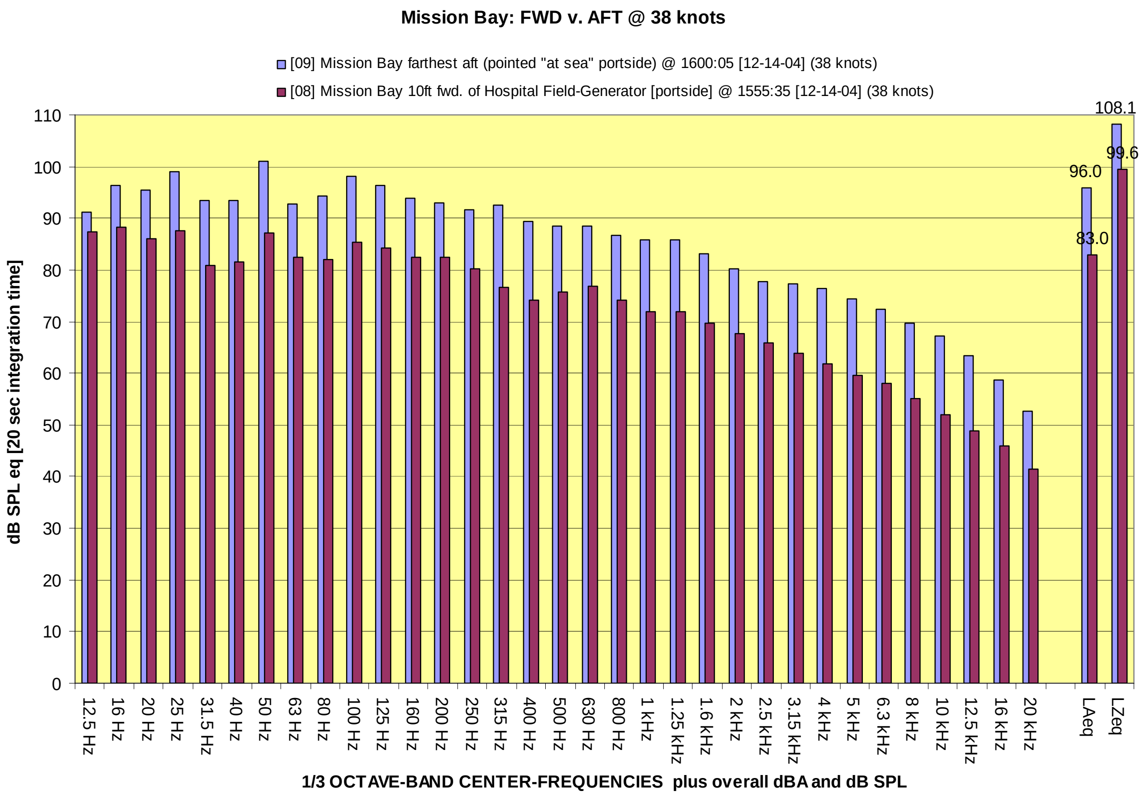

Figure 6. Mission Bay-Fwd v. Mission Bay-Aft @ 38 knots.

Location within the mission bay is a major factor in airborne noise level and is fairly consistent across the relevant 1/3-octave bands. Figure 6 compares levels measured in the forward end of the mission bay to those furthest aft, at a ship's speed of 38 knots. The aft/forward difference was 108.1/99.6 dB SPL, a delta of 8.5 dB, while the dBA values were 96.0/83.0, a delta of 13.0 dB.

Relevant to the quieter forward levels was that, despite the fact that there was a field generator running under load in the forward area just outside the BASE-X Tent, the portside airborne levels aft in the mission bay were far more intense than those measured portside just 10 ft. forward of that standard hospital field generator. Had the field generator been placed far aft, the airborne levels within any forward located shelter would have been much quieter. Critical also, would be isolation mounting of the hard-walled shelter to decouple structural vibration of the mission bay deck from the shelter structure. Standard isolation mounts designed for use under group audiometric sound booths should be located beneath the deck mounted shelters. Sound attenuation provided by properly designed shelters can reduce noise within from that in the mission bay, but with design/cost limits. Therefore, reducing the existing noise within the mission bay needs to be addressed. The port and starboard ventilation fans likely serve to reduce heavier than air combustion components from the mission bay. A shallow exhaust duct, spanning bulkhead ribs adjacent to the ventilator fan, with intakes at deck level, might reduce the fan noise with a minimum weight gain or loss of space. If not already specified, the rear mission bay

curtain may be of noise reduction design. In any case, the aft areas of the mission bay are not a desirable location for shelters that anticipate tasks requiring listening.

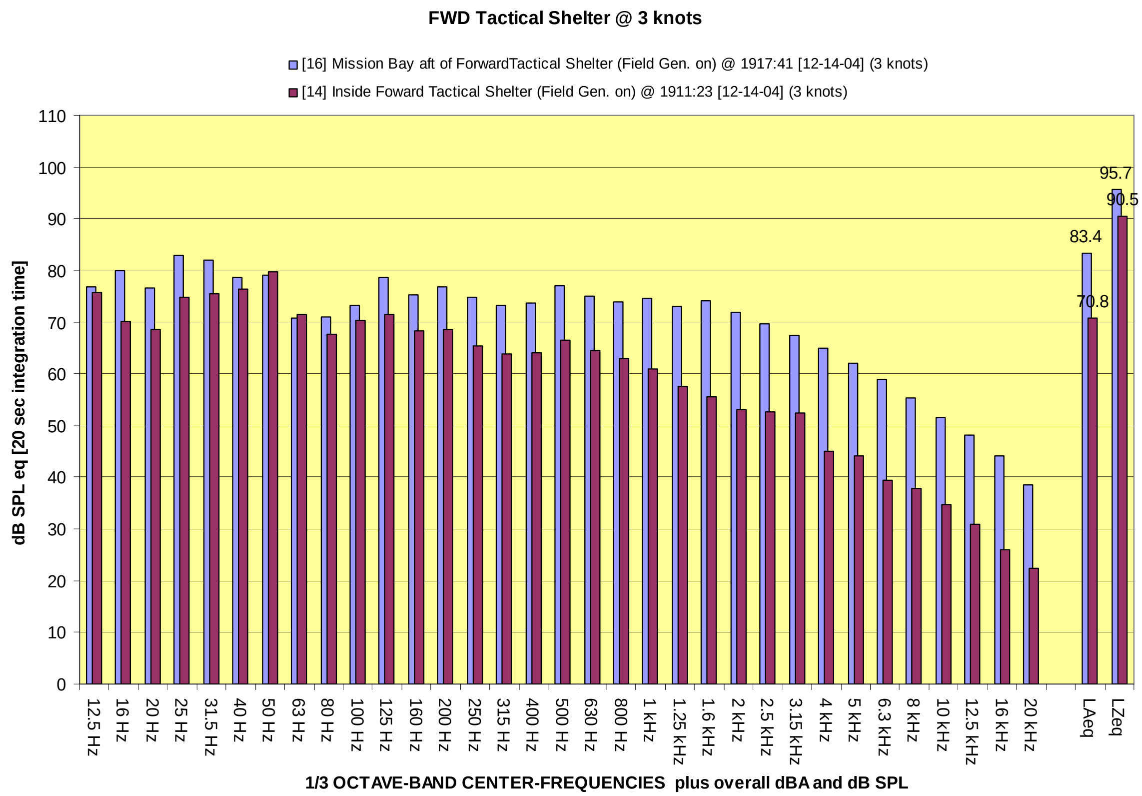

Figure 7. Inside and outside the FWD Tactical Shelter @ 3 knots.

Figure 7 compares sound attenuation characteristics of the forward tactical shelter at 3 knots, while Figure 8 (following page) compares sound attenuation characteristics of the BASE-X tent at 3 knots. Since these measurements were made later in the day, there was little activity in the mission bay. The field generator was operating near both shelters. Note that both the unweighted, and A weighted noise levels in the mission bay were essentially the same in both locations. However, comparing levels inside to those immediately outside each shelter, better noise *attenuation* was provided within the *hard-walled* forward tactical shelter. Note the level *differences*, inside vs. outside, in individual 1/3-octave bands. Those delta values identify the attenuation characteristics of the shelter divorced from outside noise characteristics resulting from location within the mission bay or ship's speed.

Passenger and berthing area noise levels are shown in Figures 9-11. Figure 9 (following page) identifies the airborne levels in the starboard passenger seating area along the center aisle. The equivalent A weighted level (LAeq) was a comfortable 66 dBA. Ship's berthing areas were even quieter.

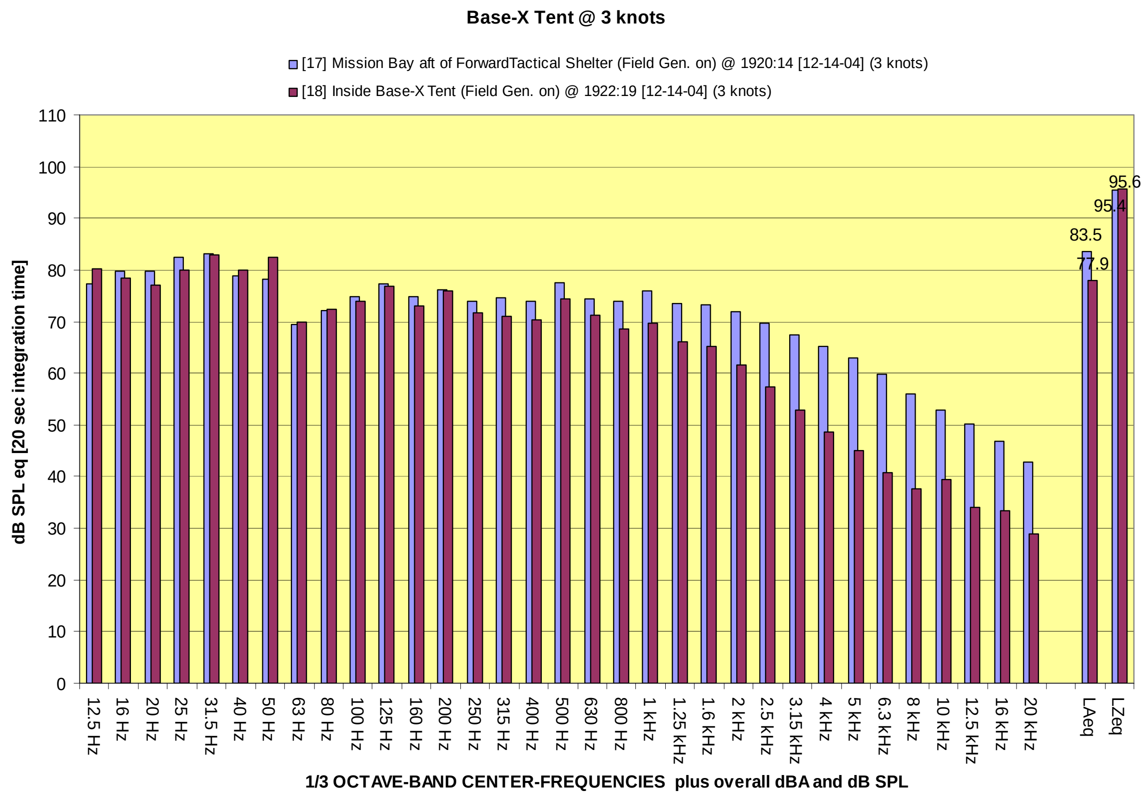

Figure 8. Inside and outside the Base-X Tent @ 3 knots.

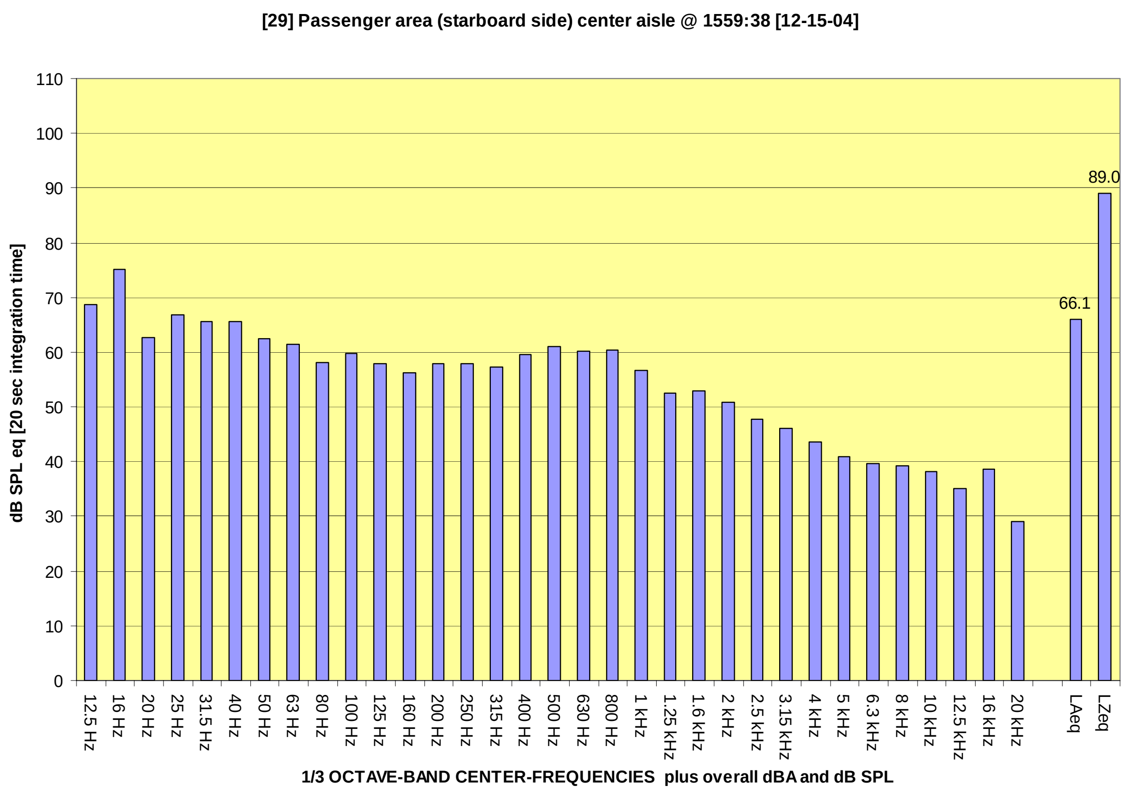

Figure 9. [29] Passenger area (starboard side) center aisle [12-15-04].

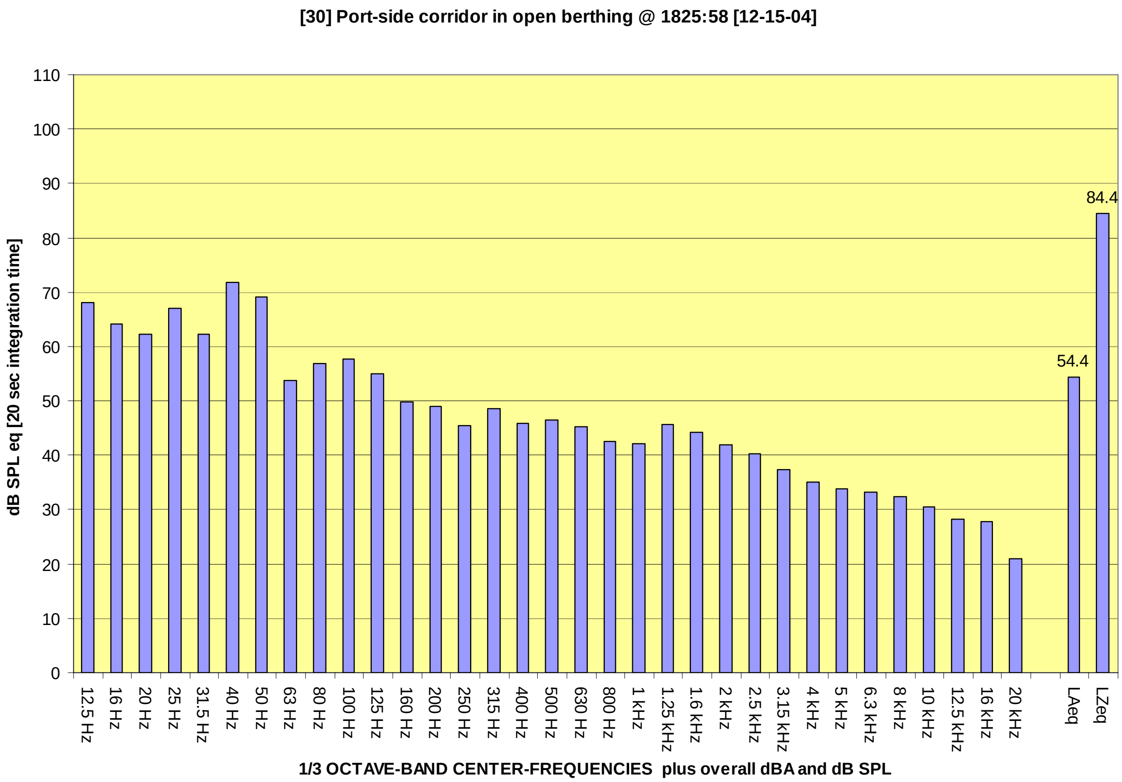

Figure 10. [30] Port-side corridor in open berthing [12-15-04].

Figure 10 identifies the airborne sound measured in the port side corridor in open berthing, which shows a LAeq level of 54.4 dBA.

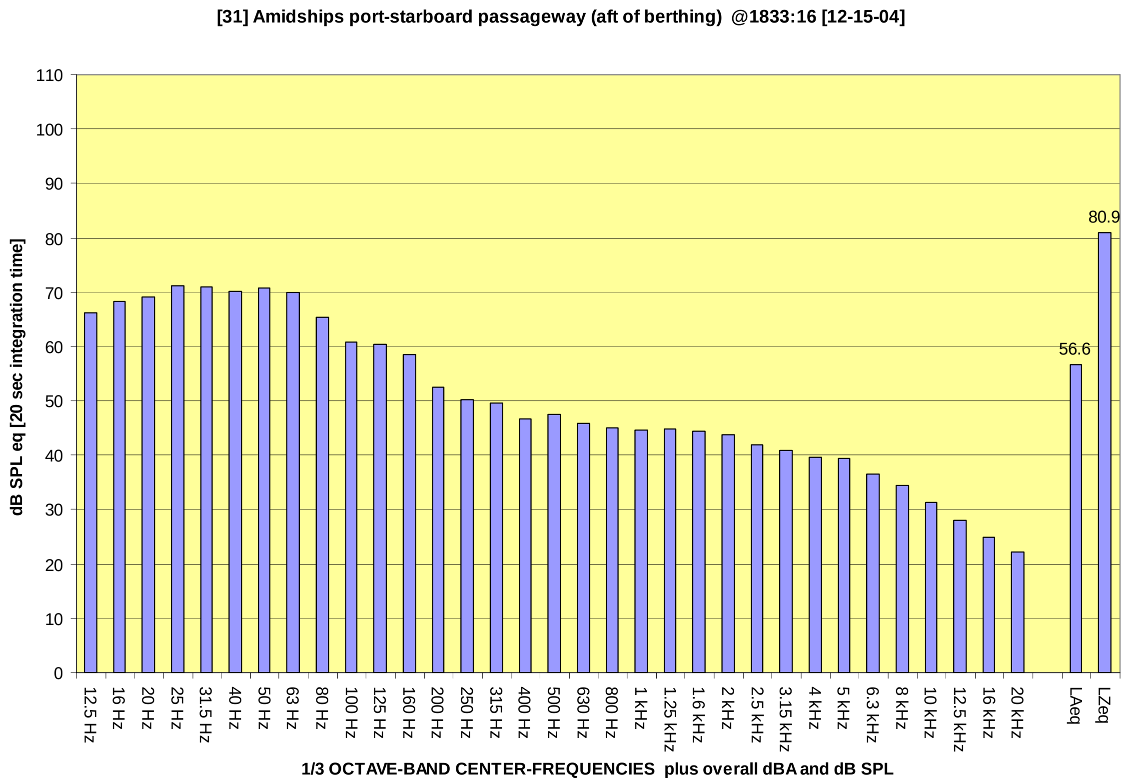

Figure 11. [31] Amidships port-starboard passageway (aft of berthing) [12-15-04].

Figure 11 shows LAeq levels further aft of berthing measured amidships in the port-starboard passageway. Again, it is apparent that design efforts were directed at habitability in areas intended for passenger occupancy.

Table 1 Results from operational evaluation questionnaire.

	Vital Sounds Stethoscope	**Conventional Stethoscope**
On improving ability to hear heart sounds in noise *	Median Response – Strongly Agree	Median Response – Undecided
	75% Strongly Agree 25% Agree	43% Undecided 36% Disagree
On improving ability to hear lung sounds in noise *	Median Response – Strongly Agree	Median Response – Disagree
	94% Strongly Agree 6% Agree	43% Disagree 21% Undecided
On improving ability to determine BP in noise *	Median Response – Strongly Agree	Median Response – Disagree
	46% Strongly Agree 36% Agree 18% Undecided**	46% Disagree 27% Undecided*

****Note**: Respondents who did not attempt BP may have indicated “Undecided” on device performance.

	Vital Sounds Stethoscope	**Conventional Stethoscope**
On improving quality of care in noise *	Median Response – Strongly Agree	Median Response – Undecided
	73% Strongly Agree 27% Agree	60% Undecided 20% Disagree
On confidence in diagnosis *	Median Response – 80% confidence	Median Response – 40% confidence
	75% Rated 80% confidence 12% Rated 100% confidence	40% Rated 60% confidence 27% Rated 40% confidence
On number of placements for confident diagnosis *	Median Response – 2 placements	Median Response – 4 placements
	73% - 2 placements 20% - 1 placement	46% - 3 placements 31% - 5 placements
On ease of use (1 best to 4 worst) No sig. difference	Median Response – 2	Median Response – 1.5
	47% - Rated 1 53% - Rated 2	50% - Rated 1 36% - Rated 2
On ability to reduce noise * (1 best to 4 worst)	Median Response – 1	Median Response – 4
	81% - Rated 1 13% - Rated 2	67% - Rated 4 33% - Rated 3
On ability to hear heart sounds * (1 best to 4 worst)	Median Response – 1	Median Response – 3
	75% - Rated 1 25% - Rated 2	47% - Rated 3 40% - Rated 4
On ability to hear lung sounds * (1 best to 4 worst)	Median Response – 1	Median Response – 3
	94% - Rated 1 6% - Rated 2	40% - Rated 4 40% - Rated 3
On ability to detect BP * (1 best to 4 worst)	Median Response – 1	Median Response – 2.5
	60% - Rated 1 40% - Rated 2	50% - Rated 2 30% - Rated 4

*** Significant at *p* less than .01**

STETHOSCOPE FIELD TESTING

During the LOE, an evaluation of a pre-production prototype Vital Sounds noise reducing stethoscope was conducted, in the shelter spaces set up in the mission bay of HSV2 SWIFT, to assess the utility of such a device for field use. Sixteen health care professionals with extensive experience in auscultation were asked to compare its performance in an AB type comparison against a conventional stethoscope in the noisy operational environment. Users completed a survey assessment form following their evaluation. Results were extremely favorable. With data analysis that showed each device was used in the evaluated tasks an equal number of times, and that users agreed favorably on the ease of placement, stabilization and comfort level of both stethoscopes, a Wilcoxon Sign Ranks Test showed there was a significant difference in ranked performance of the Vital Sounds stethoscope over a conventional device. Results for the items related to device performance are presented in Table 1, which identifies the median as well as the percentages for the top two responses. On ease of use, there was no significant difference between the two devices. When asked which device they would choose in a noisy environment, of the 15 responses, 100% chose the Vital Sounds. A Chi-Square test showed $p < .001$. It is apparent from these collective results that, in an operational setting, the Vital Signs stethoscope performs significantly better by a large margin over a conventional device.

SUMMARY

In contrast to ship-spaces designed for habitation, airborne noise in the open mission bay area would not be acceptable for certain aspects of patient care, unless mitigated by *carefully-located hard-walled* shelters. Using a conventional stethoscope to monitor even *normal heart* sounds requires, on average, unweighted dB SPL levels below 92 dB SPL. In our earlier *laboratory* testing, the ability to detect *normal heart* sounds using a Littman Classic II stethoscope was severely degraded when levels exceeded 92 dB SPL on average. There was an average 81 dB SPL upper limit for detecting *abnormal heart* sounds. Even worse, *abnormal breath* sounds could not be heard above 76 dB SPL using that standard stethoscope[1]. These results were gathered on a highly experienced sample of IDCs and two senior medical doctors. Looking at the time-integrated (LZeq) interior noise levels within the various shelters shows the need for improvement. Only in Figure 7 does the LZeq level of 90.5 dB meet the unweighted SPL requirement for even *normal heart* sounds.

The inside/outside difference in sound level, in each 1/3-octave band, reveals the sound-isolation of each shelter, divorced from location within the mission bay. Placement of the shelters, regarding both their location, relative to airborne sources of radiated energy, and isolation from structural vibration, should be paramount in lowering interior-noise. In all cases, sound attenuation becomes far less difficult, if reducing the source or even location of the noise is given consideration. Using 1/3-octave band analysis helps in identifying the presence of radiated energy ignored by exclusive use of the A weighting scale. Habitability

[1] Russotti, J.S., Jackman, R.P., Santoro, T.P., and White, D.D., Noise-reduction stethoscope for United States Navy application. Naval Submarine Medical Research Laboratory Report 1214, July 2000.

noise-standards should not be the single concern, *operational requirements* must be considered. The space is useless if the operational task cannot be done within it.

In the current field tests, the noise-reducing stethoscope proved to be a statistically significant, substantial improvement over a conventional sound-powered device. Again, noise reduction has limits. Size and complexity constraints are vitally relevant to any field device intended to safely replace a fairly inefficient simple device that, though often not-useable, has a zero failure-rate.

APPENDIX

Some relevant background on sound measurement:

Decibel (dB) is a logarithmic, rather than linear, scale that expresses the ratio between two values. Unlike a linear scale like feet or inches, 2 is not twice the magnitude of 1. The decibel was originally developed to specify the voltage gain in amplifiers, but has taken on other applications.

For sound measurements, when we specify dB SPL (Sound Pressure Level), that ratio is referenced to a barometric pressure of 20 micro Pascal (20μPa) which then becomes 0 dB SPL. The term 100 dB SPL then identifies a pressure 100 dB greater than 20μPa.

In the figures presented in this report, the overall dB SPL value is shown as the bar at the far right. Unfortunately a single number tells little about the distribution of energy that caused that level. The 33 individual bars that start on the left at 12.5 Hz and end at 20kHz provide more relevant information on where the sound energy is greatest. That distribution adds up to the single overall dB SPL value shown on the right in each figure.

Since human hearing is limited in frequency range, a filter was developed to create weighting scale that mimics the response of the human ear. This is the A weighting scale, and its filter characteristics are shown in Figure 1 in the report. Unlike the linear SPL scale, the relative contribution of frequencies below 1000 Hz is reduced[2]. When the unfiltered SPL signal is passed through the A weighted filter, the measurements are abbreviated dB(A) or now commonly dBA.

For *habitability* requirements only dBA is monitored for ships design. However, for human *operability* issues, like passive sonar listening or, as in our case detection of vital sounds, these other frequencies often interfere with operationally essential listening tasks.

In our controlled laboratory testing, the ability to detect *normal heart* sounds using a Littman Classic II stethoscope was severely degraded when SPL levels exceeded 92 dB SPL. Even worse, *abnormal breath* sounds could not be heard above 76 dB SPL using that standard stethoscope. Using the noise reduction stethoscope allowed detection of *abnormal breath* sounds at around 91 dB SPL[3]. The greatest improvements, using the noise reduction stethoscope, are found for abnormal rather than normal visceral sounds. In fact, these are the most operationally relevant. Unfortunately, subjecting patients exhibiting abnormal visceral sounds to field tests becomes complicated.

In an earlier evaluation onboard USS Kearsarge, we were able to hear *normal heart* sounds using a prototype electronic noise-reducing stethoscope (Vital Sounds) at levels of 96 dB SPL. Those evaluations were made in non-medical ships spaces to demonstrate the capability of the noise-reducing stethoscope over a conventional device for field use in ships spaces. At that noise level these sounds could not be heard with the conventional stethoscope. These field findings agree with our laboratory results, which showed a 5 dB improvement for detection of *normal heart* and a 6 dB improvement for detection of *abnormal heart* sounds over a normal stethoscope.

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[2] E.g. the "A" level is reduced approximately 10 dB @ 200Hz, 20 dB @ 100Hz, and 30dB @ 50Hz.
[3] Russotti, J.S., Jackman, R.P., Santoro, T.P., and White, D.D., Noise-reduction stethoscope for United States Navy application. Naval Submarine Medical Research Laboratory Report 1214, July 2000.

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14. ABSTRACT
Throughout NSMRL's pursuit in making optimal use of auditory information in sonar displays, interference from airborne sound in the listening environment has been a major issue. NSMRL's success in using active noise cancellation to prevent masking by airborne sound has lead to the realization that shipboard spaces may be habitable by hearing-risk standards, but not operationally suitable for critical mission tasks. Digital sound processing has opened up the auditory detection, display and transmission of information in inherently noise environments. This Medical Limited Objective Experiment (LOE) was valuable both to evaluate the noise environment in spaces not designed for habitation, and to simultaneously test a pre-production noise-reducing stethoscope in a controlled setting under operationally-relevant shipboard noise conditions. In the field tests, the noise-reducing stethoscope proved to be a statistically significant, substantial improvement over a conventional sound-powered device.

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